

EXECUTIVE SUMMARY

Introduction

This executive summary provides background to the mining induced subsidence events in Collingwood Park and outlines CSIRO's technical report into these events.

CSIRO explains why the events occurred and provides options that if actioned, could help prevent future mining-related subsidence.

This summary does not outline the costs associated with CSIRO's suggested options. The CSIRO report is a technical one and costs were not part of the terms of reference.

Background

Part of the Ipswich suburb of Collingwood Park is underlain by two decommissioned underground coal mines – Westfalen Number 3 and New Redbank Collieries. These mines used the “bord and pillar” method of mining at depths from approximately 60m to 140m.

Bord and pillar mining at the collieries created numerous underground pillars ranging up to 11m in height in some areas of Westfalen Number 3, and with various dimensions and shapes left behind to support the load from the rock above the mine after coal was extracted.

In mining terminology, the *Factor of Safety* (FoS) is a measure of stability, defined as the ratio of the maximum strength of a pillar to the load applied to the pillar. A low FoS implies a high risk of mechanical failure. If the calculated FoS is lower than the requisite value, a pillar may fail, triggering overload of neighbouring pillars, leading to roof failure and caving of rock above pillars into the previously excavated roadways or mine voids, and ultimately ground subsidence which may penetrate to the surface.

In December 1988, a subsidence event occurred near Lawrie Drive, Milgate Street and Rush Court in Collingwood Park. In April 2008, a second subsidence event occurred, resulting in surface movement and damage to houses within an area near the intersections of Duncan, McInnerney, McLaughlin and Moloney Streets. Both subsidence events occurred as a result of pillar failure within the Westfalen No. 3 Colliery.

Westfalen No. 3 Colliery

The Westfalen No. 3 Colliery extracted coal from the Ipswich Coal Measures from 1965 to 1987. At this mine, multiple coal seams coalesce into a single seam more than 11m thick. The full thickness of the seam was mined in some areas, while in other areas only part of the seam was mined.

Bord-and-pillar mining at Westfalen No. 3 initially used *ad hoc* pillar designs, but after 1976 a modern pillar design was employed. This latter method, characterised by regular square shaped pillars designed to a specific FoS, is evident in the panels to the east of Kruger Parade. To our knowledge, these pillars are still stable (the term “panels” denotes a collection of coal pillars that are spatially and geometrically grouped).

Earlier *ad hoc* mining resulted in irregularly shaped pillars of varying height. Inundation of Westfalen No. 3 in the major flood of 1974 caused pillar damage and roof and floor scouring. Some of these *ad hoc* pillars in the panels that were mined early in the life of Westfalen No. 3 have collapsed, resulting in the 1988 and 2008 surface subsidence events.

CSIRO Engagement

At the request of the Department of Employment, Economic Development and Innovation (DEEDI) and the Department of Infrastructure and Planning (DIP) of the Queensland Government, CSIRO studied mining-induced subsidence at Collingwood Park associated with the Westfalen No.3 Colliery with the goal of providing options for prevention of future mining-related subsidence.

This Executive Summary describes CSIRO's Final Technical Report that documents a 12-month work program.

Numerical modelling by CSIRO estimated the present stability of the workings in order to understand the effectiveness of remediation methods. These models are limited by complex and uncertain subsurface mine geometry and unknown parameters in mine working details. It is unlikely that further field investigation will reduce this uncertainty significantly.

Stability Analysis

Observed ground subsidence directly indicates pillar and/or panel failure. CSIRO assessed the stability of underground panels using the modern pillar design approach to estimating pillar strength from pillar width and height. CSIRO found that pillar strength in the two already failed panels was well below that required for long-term stability where pillars are located beneath a residential area, validating the overall modelling method.

CSIRO estimated that the Central Panel is approximately 20% stronger than the adjacent panel to the south-west that failed in 2008. Further, CSIRO estimated that, of the areas studied, the Central Panel is the next most likely to subside in the future, and that remediation is needed to ensure long-term stability of the Central Panel.

A three-dimensional seismic investigation suggested that pillar collapse in 2008 may have damaged pillars in the Central Panel, reducing its Factor of Safety and compromising its integrity.

CSIRO considers that, if another panel failure occurs, the event will be characterised by failure of one or more pillars and subsequent load transfer to adjacent pillars, resulting in over-stressing and further cycles of pillar failure and load transfer until barrier pillars or unmined coal halt the process. Given the irregular nature of the pillars and the widely varying geometrical attributes of width and height, CSIRO considers that the resulting failure will develop gradually over hours or days rather than an uncontrolled violent manner known as cascading pillar failure. CSIRO also considers that the surface expression of any potential failure will be subsidence developing to a magnitude comparable with the 2008 event (approximately 1.5m).

Monitoring

CSIRO recommended a monitoring system combining a micro-seismic network to monitor seismic events as a result of fracturing in coal pillars and rock strata above the coal seam with an extensometer installed deep in a borehole to monitor deformation of the rock strata focused on the Central Panel. This recommendation has been accepted by the Queensland Government. The hybrid monitoring system is in place and is working as designed. Early results from the monitoring system have identified minor seismic events and some potential stratal deformation. Some of seismic events may be associated with the 2008 failure and the monitored strata movement may partially be instrument related.

From the monitoring results to date, CSIRO considers that parts of the Central Panel are moving slowly. Accordingly, CSIRO recommends that additional extensometers and an additional seismic station be installed above the Central Panel to increase the accuracy and reliability of the monitoring network. Should there be significant increases in the seismic events and/or the rate of deformation, these indications would suggest increasing potential for a surface subsidence event.

Gas

CSIRO considers that rapid escape of mine gas to the surface is possible but unlikely in the case of non-violent panel failure.

Tests conducted by Simtars determined that the mine gas is typical of an unventilated closed coal mine and is a mixture of methane, carbon dioxide, nitrogen and oxygen. Combustion of this gas mixture at the measured levels is not possible. However, if mine gas escapes to the atmosphere, the resulting mixture could potentially be combustible until dispersed. Further monitoring is needed.

Water

Apart from inundation in the 1974 flood event, Westfalen No. 3 Colliery was considered by mine managers to be a dry mine with little water ingress. Existing studies and piezometer monitoring indicate that the workings are currently partially flooded, with rising water levels. Because the CSIRO study coincided with above average rainfall in southeast Queensland, long-term trend of water levels cannot be determined from a single snapshot of current monitoring data.

Rising water levels will reduce coal pillar strength to an uncertain degree. CSIRO determined that the pillars that failed in 2008 were not affected by water. However, it is not known if rising water level was associated with the 1988 subsidence. CSIRO recommended investigating the influence of water interacting with the coal of the specific mineralogy of the Westfalen No. 3 mining seam, because these results could influence the stability assessment and remediation options for the Westfalen No. 3 Colliery. Future work will require studies to assess potential for leaching, erosion, pollution and migration of chemical elements in the fly ash into the underground water.

Backfill Remediation

CSIRO investigated a range of remediation options to reduce the likelihood and consequence of future mine-induced surface subsidence. Backfilling mine voids was identified as the most likely method to achieve success.

CSIRO and University of Queensland researchers tested mixtures of fly ash, crusher dust, sand, cement and water for flowability, stability, strength and overall suitability as potential backfill material. These mixtures included a non-cohesive mix of fly ash and water to a 50-60% solids-water concentration, and a cohesive mix that adds cement to the non-cohesive mix to give a conservative 0.5MPa strength backfill.

The major advantage of the non-cohesive mix over the cohesive mix is that its properties do not change rapidly with time and can penetrate more reliably into smaller voids. This reduces the number of holes needed to be drilled for filling when compared to a cohesive mix. Flowability tests indicate that 90% fill of the mine voids should be achievable, particularly and preferably with a non-cohesive mix.

CSIRO estimated that after backfilling, a typical Westfalen No. 3 coal pillar would be approximately 30% stronger using the non-cohesive mix and 57% stronger using the cohesive mix if the surrounding mine voids are filled to 90%. Panel strength increases resulting from backfill are predicted to be of a similar magnitude.

Unstable pillars, and pillars that have already failed, should become stable after confined bulk filling. Modelling indicates that backfilling to 90% with a non-cohesive mix will increase pillar FoS to a minimum of 1.6, the value often used in rock engineering design for long-term stability.

CSIRO recommended bulk filling of the mine voids with a fly ash mixture from the nearby Swanbank Power Station. A similar approach has been adopted to ensure mine pillar stability as part of the nearby Ipswich Motorway Upgrade.

CSIRO considered two backfilling options in detail. **Option 1** is isolation and subsequent backfilling of the Central Panel, and **Option 2** is the backfilling of all Westfalen No. 3 mine voids that undermine the Collingwood Park residential area northwest of Lawrie Drive and east of Collingwood Drive. CSIRO considered the strength improvement and associated risk reduction together with the potential consequences for both options.

CSIRO assessed undermined areas to the west of Collingwood Drive within the project boundaries, based on the Factor of Safety calculations, as stable for the long-term due to the shallower mining depths and bigger pillars used and were therefore not considered in either option.

Option 1 strengthens the Central Panel, identified as the area of Westfalen No. 3 where future pillar failure is most likely. However, it does not reduce the subsidence risk in areas other than the Central Panel. It also requires building underground barrier walls around the Central Panel which are often expensive, making it less cost-effective than Option 2.

Option 2 strengthens all Westfalen No. 3 mine voids that undermine the Collingwood Park residential area north-west of Lawrie Drive and east of Collingwood Drive, increases the calculated FoS to 1.6, believed to be sufficient for the long-term stability of coal pillars, and minimising potential for mine-induced surface subsidence. Even in the unlikely event of pillar failure after backfilling, CSIRO estimated surface tilt will be less than 5mm/metre, which would result in insignificant to minor damage to the existing Collingwood Park housing stock of slab on ground dwellings.

*CSIRO recommended that the Queensland State Government use remediation **Option 2** with non-cohesive backfill, i.e. backfilling all open mine voids of the Westfalen No. 3 Colliery north of Lawrie Drive and east of Collingwood Drive using a backfill grout consisting of fly ash and water with 50-60% solids-to-water concentration to a minimum of 90% void volume.*

CSIRO recommended that this remediation be undertaken as soon as outstanding environmental and technical issues are resolved.

Further Studies Ensuring the Successful Remediation of Westfalen No.3 Colliery

A backfilling project of this scale has to CSIRO's knowledge not been previously attempted. The table below summarises CSIRO's recommendations to resolve the technical and environmental issues necessary to proceed with remediation of Westfalen No. 3 Colliery.

Table: Summary of further studies to ensure the successful remediation of Westfalen No.3 Colliery

Recommendation	Scope	Reason	Duration
Expansion of the existing monitoring network	Install two additional extensometers and one micro-seismic station in the Central Panel. The existing monitoring network consists of one extensometer and three seismic stations	<ol style="list-style-type: none"> 1. Verify if sections of the Central Panel are stable or deforming. 2. Improve the accuracy and reliability of the monitoring system for any future mine related surface subsidence event, if any. 	2 months
Large scale laboratory modelling of backfill	Build a scaled-down bord-and-pillar mine model in laboratory; conduct injection tests by injecting different grout materials into the mine voids; observe the process of backfilling.	<ol style="list-style-type: none"> 1. Simulate to verify various injection scenarios for the ability to achieve the critical minimum 90% fill. 2. Understand both visually and analytically the process of backfill and its effect. 	8 months
Field full scale test of roadway backfill	Excavate a mine roadway-sized trench at the surface; carry out a full-scale grout injection operation; measure grout flow details including profile and distance in the backfilling process.	Determine potential backfilling issues that can arise in the actual underground backfill operation. Ascertain the most effective and optimum backfilling procedure and process for the real underground mine backfill operations.	8 months
Water: effect of rising levels	Conduct a focused study to quantify the effect of rising water in Westfalen No.3 on the ground stability, including laboratory tests of dry and wet coal samples and analytical/numerical modelling.	<ol style="list-style-type: none"> 1. Understand the effect of rising water level on ground stability; 2. Determine if pumping out mine water before or during backfill operation is needed. 	10 months
Water: groundwater quality after backfill	Investigate and monitor groundwater flow and chemical transport during and after fly ash backfilling; predict the effect of fly ash back fill on groundwater quality.	Determine whether or not backfilling and backfill mix will cause any unacceptable concentrations of any potentially harmful elements in the underground water system.	8 months
Continuous ground monitoring and data analysis, including gas	Maintain the monitoring system in working condition; analyse and interpret the data on a weekly basis before and during backfilling, and monthly after backfilling; recommend actions if subsidence risk is found to increase; continue monitoring during and after backfilling for the long term.	<ol style="list-style-type: none"> 1. Develop a historical record of the current geotechnical environment. 2. Identify any trends suggesting an increased potential for future subsidence events 3. Assess effect of backfilling on ground stability in both short and long-term periods. 	Ongoing (until risk is considered to be fully controlled)

New Redbank Colliery

New Redbank Colliery mined coal during the 1920s in an area that now underlies the north-east corner of Collingwood Park. Coal was extracted from the Bluff, Middle and Bottom seams in a pattern that resulted in overlapping mine panels at different elevations. This approach is called *multi-seam mining*.

Stability assessment of New Redbank Colliery is difficult because few reliable data exist that describe mining operations. A mine plan exists, but its accuracy has not been confirmed and little additional information is available on mining heights and working conditions.

CSIRO believes that further investigation of New Redbank Colliery is needed to establish what remediation may be necessary.

Summary of Recommendations

1. Backfill all open mine voids of the Westfalen No. 3 Colliery north of Lawrie Drive and east of Collingwood Drive using a backfill grout consisting of fly ash and water with 50-60% solids-to-water concentration to a minimum of 90% void volume.
2. Expand the existing monitoring network in Collingwood Park by installing two additional extensometers and one micro-seismic station above the Central Panel of the former Westfalen No. 3 Colliery.
3. Conduct a large-scale laboratory modelling of backfill.
4. Conduct a full-scale field test of roadway backfill.
5. Conduct a focused study to quantify the effect of rising water in Westfalen No.3 on the ground stability.
6. Investigate and monitor groundwater flow and chemical transport during and after fly ash backfilling
7. Continue ground monitoring and data analysis, including gas, in Collingwood Park.